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MBA PROFESSIONAL REPORT

Ubiquitous Power; Opportunities and Benefits of the Photo-Voltaic Power Converter for the Individual War Fighter

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December 2004

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The success of every military throughout history has been its ability to move, shoot, and communicate, which require power. In the modern era, technology has afforded military soldiers with the equipment that greatly enhances maneuverability through state of the art communications equipment. Such equipment creates significant power needs that are currently met through the use of expensive and heavy to carry disposable and rechargeable batteries. The limitation for improved complex communications, as well as weapon systems, is the ability to power such systems. The problem with alternative power sources has been the inefficiency, reliability, and convenience of such systems. This project provides an analysis of a new ubiquitous power source (Photo-Voltaic Power Converter) and the opportunities it can afford to individual soldiers in meeting existing power requirements. This paper calculates the savings and reports on critical user needs of the individual war fighter.

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UBIQUITOUS POWER; OPPORTUNITIES AND BENEFITS OF THE PHOTO-VOLTAIC POWER CONVERTER FOR THE INDIVIDUAL WAR FIGHTER

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

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PHOTO-VOLTAIC POWER CONVERTER

ABSTRACT

The success of every military throughout history has been its ability to move, shoot, and communicate, all of which require power. In the modern era, technology has afforded soldiers with equipment that greatly enhances maneuverability through state of the art communications equipment. Such equipment creates significant power needs that are currently met through the use of expensive and heavy to carry disposable and rechargeable batteries. The limitation for improved complex communications, as well as weapon systems, is the ability to power such systems. The problem with alternative power sources has been the inefficiency, reliability, and convenience of such systems. This project provides an analysis of a new ubiquitous power source (Photo-Voltaic Power Converter) and the opportunities it can afford to individual soldiers in meeting existing power requirements. This paper calculates the savings and reports on critical user needs of the individual war fighter.

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I. INTRODUCTION

A. GENERAL

The United States Army is actively seeking technology to facilitate its goal of transforming its troops into a more agile force. One such program is called “Objective Force Warrior”, which seeks to develop and demonstrate revolutionary capabilities that enable the Army soldier to do more while carrying less. The goal is to make soldiers more self-sufficient through technology, but the equipment associated with this more agile force is constrained by the power requirement involved with sustaining such equipment.

“Objective Force Warrior” covers advancements on multifunctional sensors, networked communications, and positioning navigation, among other initiatives. However, all these initiatives require a reliable energy source that is efficient and inexpensive compared to current practices utilizing batteries and generator sources. The power generation requirement is currently unsolved because of the inefficiencies associated with alternative and natural power sources.

This research project involves a new low-light solar power generation device, developed by Atira Technologies, which is the answer to the power generation requirement. This device is named the Photo Voltaic Power Converter (PVPC) and the project focuses on developing Atira’s concept into a product that can be used by military forces. This product is able to provide power at the needed power levels continuously over extended periods of time in operational environments. This technology not only solves the power requirements of the Objective Force Warrior program, it can save millions of dollars as compared to the current practices using generators and batteries.

B. BACKGROUND

Solar power technology in the 1970’s had great potential and promise as an alternative energy power source. However, solar power became one of the great disappointments of the energy sector as the technology of solar cells failed to advance. Current solar cells operate at about 8% efficiency (state of the art solar panels used by NASA may go as high as 28% efficiency) with a loss of 30% in the transfer of electrical power to a chemical storage battery, and then another loss of 30% in the transfer of chemical energy back into electrical energy. This inefficiency is compounded by the requirement that solar panels be focused on the sun to produce maximum power.

Another limiting factor is that charging a chemical battery requires a power level in excess of the rated power of the battery. For example, a 12-volt battery in an automobile requires a charging voltage between 13.5 volts and 14.7 volts. This charge state can be achieved by a solar panel in direct sunlight by a solar panel of sufficient size. However, if the solar panel loses its direct orientation to the sun and its power output drops below the charging zone of the battery, the charging process terminates. Further, the angle of the sun must be greater than 45 degrees to the horizon. This limits the available charging time to about 25% of the 24-hour day (on average). The higher the latitude, the less time is available. This phenomenon also decreases charging capacity during overcast or humid conditions.

C. OBJECTIVE

The objective of this project is to research the warfighters' needs to determine individual soldier power requirements, and how to make the technology convenient and useful.

D. SCOPE

This project examines the integration and application of the PVPC for the use of the individual soldier. This project is limited to the individual soldier's current power requirements.

E. RESEARCH QUESTIONS

1. Primary Research Question

Will the PVPC meet the power requirements of an individual soldier's electrical and electronic devices associated with the combat load, and if so, how can the technology be implemented without adding to the combat load?

2. Secondary Questions

- What does the individual soldier want/need in terms of power requirements?
- Does the technology need to be incorporated into the equipment of the combat load or should it be a stand alone unit?

- What are considerations in the design from the view point of the war fighter?

F. METHODOLOGY

The research for this project includes:

1. Face-to-face interviews for a qualitative analysis of the military user's needs and expectations. These interviewees were derived from the Army student body at the Naval Postgraduate School with various backgrounds in combat operations, logistics, and technical military occupations. The interviews followed a thirty minute demonstration of a proto-type of the PVPC technology conducted by Stefan Mahan, Atira engineer. Once the demonstration was complete the users were allowed time to ask questions. The users were asked questions by the researcher to elicit requirements based on each user's experience and occupation specialty in the Army. These Army Officers made an ideal sample because they collectively represented all areas of the Army organizational structure.
2. An analysis of the interviews along with any gathered secondary data helped the researcher pull together the recommendations for the product features, application, usability, durability, as well as functional requirements that can be used by Atira for future design considerations.
3. A literature search of books, articles, reports from the Army Research and Development Command and from Army Systems Research.

G. ORGANIZATION

1. Chapter II. Product Background and Description

This chapter provides background information on the development of the PVPC. It includes information on the inventor and his qualifications in order to validate the expertise behind the device.

2. Chapter III. Soldier Power Requirements and the PVPC

This chapter reports the results of the information obtained from the U. S. Army's Research, Development, and Evaluation Command. Based on the information gathered from the research command, this chapter determines the individual power requirements of a typical soldier compared to the opportunities of the PVPC and calculates potential savings in cost and weight.

3. Chapter IV. User Familiarization and Feedback

This chapter reports user feedback based on a proto-type demonstration conducted at the Naval Postgraduate School in Monterey, California.

4. Chapter V. Conclusions and Recommendations

This chapter discusses conclusions and recommendations based on the analysis conducted in Chapters III and IV.

II. PRODUCT BACKGROUND AND DESCRIPTION

A. PRODUCT BACKGROUND

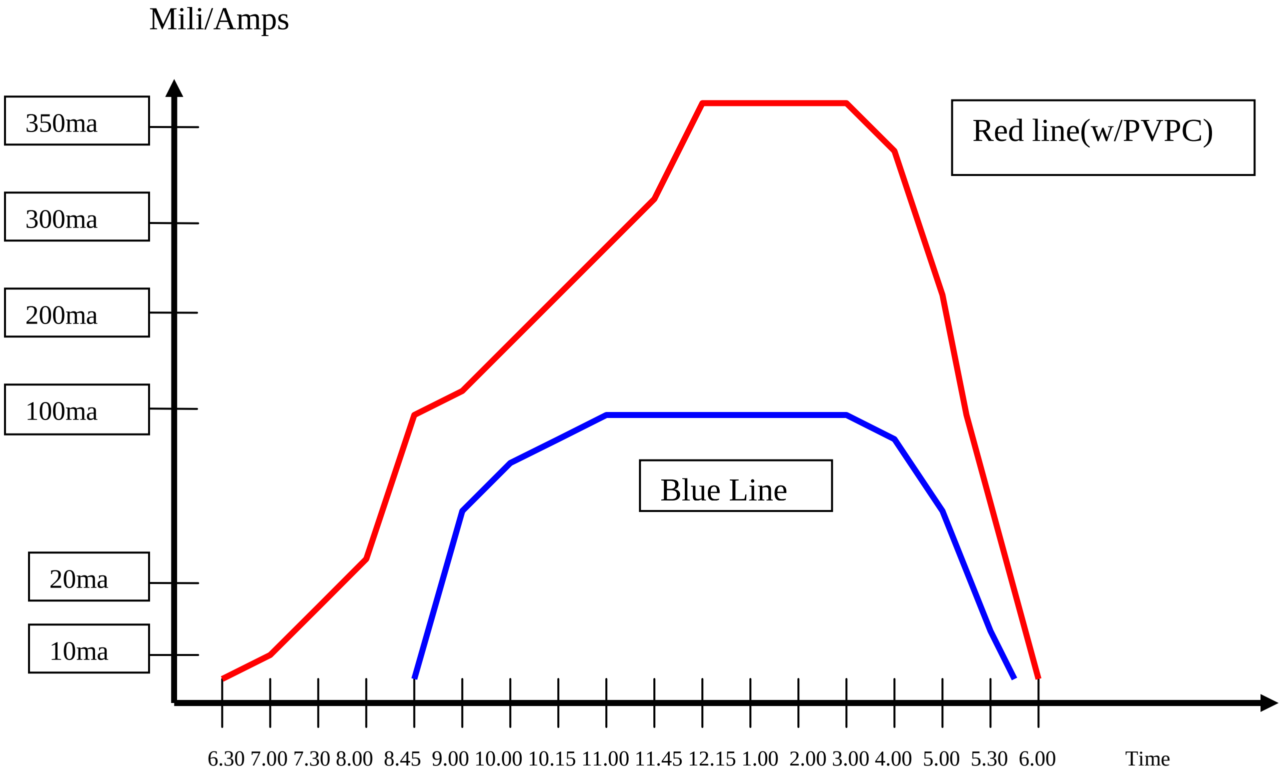
This research project is focused on the application of a new control technology developed by Atira Technologies. Atira is located at 233 Oak Meadow Dr., Los Gatos, California. The company was founded by Stefan Matan and is a research and development company. The Photo-Voltaic Power Converter (PVPC) allows a solar charger to charge a battery even though the power output from the solar panel has dropped below the threshold charging requirement of the battery.

Successfully developing this technology has dramatic economic and operational impacts for the Department of Defense (DoD). Soldiers (including Sailors, Airmen, and Marines) in an operational environment must carry disposable batteries for their various electronic systems (radios, GPS, flashlights, etc.) For safety purposes, in an operational environment, a soldier should actually carry a surplus of 20% of the expected battery power usage. Weight constraints and the cost of these batteries, multiplied by the number of soldiers using them, are very high. A study conducted by the Army for one platoon on a five day mission put the cost of batteries at $13,000 (Natick Study).

Replacing disposable batteries with rechargeable batteries is a strategy that has been considered by operational units in the past. However, recharging the rechargeable batteries is problematic due to units deployed in forward positions without vehicles or generators. The lack of an efficient charger is tantamount to having no batteries at all.

The low light solar charger has the potential to increase charging time efficiency up to 50% of the 24-hour day, and still be able to charge in overcast conditions. The following graph displays the results of a test conducted on September, 29 2004. The test measures usable charge in m/amps of two solar panels over a one solar day period. One solar panel was connected to the PVPC (red line) and the other panel was not (blue line). Each panel was then connected to a 12 volt rechargeable battery. This test clearly shows the advantages of the PVPC by the difference in time and deliverable current/power during the daylight hours.

Figure 1. PVPC Test Recharging 12V Battery



Batteries are considered hazardous materials and must be disposed of as such when they are no longer usable. Rechargeable batteries have an obvious cost advantage since they can go through hundreds of recharge cycles.

B. PRODUCT DESCRIPTION

The current charger prototype developed by Atira is about the size of an external computer modem and has a weight of 2.8lbs. (See figure 2) It has a charge hold of 13.8 v and can discharge 9.9 amp/hour. It has an output of 12 VDC or 110 VAC. The charging range is between 2.5V to 15V and it can be charged either by solar, fuel cell, wind turbine, regular batteries, or any energy as low as 2.5V. It is capable of low light charging and maximum power point tracking. This means the solar panel being used does not have to be oriented toward the sun. In fact, the panel can be oriented away from the sun and still maintain a usable charge. It can charge four AA 1.5V batteries in 20 minutes and it can charge a 24V 15 amp/hour battery in six to eight hours. It currently has a shelf life of one year (-10%) discharge. The internal wafer batteries within the system have no memory effect and include smart technology to allow for charging and discharging simultaneously. The wafer batteries have a life cycle of 560 recharge cycles. A test being conducted has the prototype operating a commercial GPS device 24 hours a day seven days a week.

The complete system is composed of the following subcomponents. (See Figure 2)

Low Light charger (Photo-Voltaic Power Converter)

The Low Light charger converts the power produced by a Photovoltaic Panel (Solar Panel) to a DC electrical current that charges the battery. Aspects of its design are unique and allow usage of a solar panel over an extended range of lighting conditions.

Batteries (Waffer Configuration)

The non-replaceable batteries used are known as “Smart” batteries. Their circuitry protects them from over charging and excessive load conditions. They are Lithium based batteries, light weight, and contain no hazardous materials.

DC to 110 VAC Converter

The DC to 110VAC Converter is a very efficient switch mode converter, which includes circuitry that stops the converter’s operation when the batteries discharge to their minimal value. The circuitry will not turn on again until the batteries have charged to approximately 30% of their operational capacity. This allows the batteries to operate in a discontinuous fashion, both charging and discharging the battery.

12 VDC Connection

A generic 12V Receptacle is available for those devices that require this form of connectivity.

Accelerated charge connector.

The internal batteries can be charged at an accelerated rate if so desired. 12VDC applied to this connection charge the batteries in approximately 20 minutes.

Figure 2 shows a state of the art unit under development. It is capable of delivering energy for 10 hours at a 1 Amp discharge rate. An older version of the unit was tested in Afghanistan where the unit was used to charge a variety of batteries. The most recent test conducted with the unit below recharged a BA2590 (Sincgars radio rechargeable battery) in seven hours in low light conditions. This test was conducted upon the request of MARCORSYSCOM (Marine Corps Systems Command) with the requirement of being able to recharge the battery in one solar day. The task was completed well under the requirement.

Figure 2. PVPC proto-type

The prototype can be configured to recharge all types of batteries depending on user requirements and electronic devices. This project identifies the potential range of military utility provided by information gathered through research and interviews of users described in chapter one.   The data collected here will also be used by Atira for future designs for product development that is more aligned for military utilization.

III. SOLDIER POWER REQUIREMENTS AND THE PVPC

A. INDIVIDUAL SOLDIER POWER REQUIREMENT DETERMINATIONS

The crucial element of all research to improve individual warrior systems is the power source that sustains the electronic devices in use today, and those not yet developed. The power requirement of devices not yet developed is difficult to determine and are outside the scope of this research.

The primary source for existing power requirements are disposable and rechargeable batteries. In order to determine existing power requirements, the research must be conducted by looking at the type of equipment an individual soldier uses and the battery power sources associated with that equipment. This analysis makes it possible to determine how the PVPC can best be utilized to meet individual soldier power needs.

The data contained in Tables (1), (2), (3), and (4) was obtained from the Objective Force Warrior Program of the United States Army. The data is based on a 5 day mission of a platoon size force in field conditions. The data is broken down to each soldier within a platoon and it details the equipment used, the batteries required for each piece of equipment, and the number of batteries needed each day for each piece of equipment. The data states the power requirement in watt/hours, weight, volume, and cost of batteries associated with each soldier. A five day mission for a typical platoon size force requires 933 batteries (see Table 1) consisting of seven different battery types at a total cost of $12,991. (see Table 4) The total weight is 162 pounds (see Table 3) with a volume of 3,102 cubic inches. The total power requirement is 11,285 watt/hours. (see Table 2) These totals are illustrated below.

Table 1. Platoon Electronic Equipment and Battery Usage 5 day mission analysis

5 day mission									
	Battery Count		LTWS/PAQ						
		MELIOS	PEQ/PVS	CCO	HTWS/M	PRC126	PRC119	PLGR	
	Duty Position	BB516	BA3058 (AA)	BA5123	BA5347	BA5588	BA5590	BA5800	Total
	PL Ldr	1	8	2	10			7	28
	PL Sgt	1	8	2	10	2	4	7	34
	RTO		8	2		2	4		16
Squad 1	Sqd 1 Ldr		8	2	10	2		7	29
	Rifle Team A Ldr		8	2					10
	Grenadier		4	2					6
	Auto Rifleman		8		10				18
	Rifleman		88	2					90
	Rifle Team B Ldr		8	2					10
	Grenadier		4	2					6
	Auto Rifleman		8		10				18
	Rifleman		88	2					90
Squad 2	Sqd 2 Ldr		8	2	10	2		7	29
	Rifle Team A Ldr		8	2					10
	Grenadier		4	2					6
	Auto Rifleman		8		10				18
	Rifleman		88	2					90
	Rifle Team B Ldr		8	2					10
	Grenadier		4	2					6
	Auto Rifleman		8		10				18
	Rifleman		88	2					90
Squad 3	Sqd 3 Ldr		8	2	10	2		7	29
	Rifle Team A Ldr		8	2					10
	Grenadier		4	2					6
	Auto Rifleman		8		10				18
	Rifleman		88	2					90
	Rifle Team B Ldr		8	2					10
	Grenadier		4	2					6
	Auto Rifleman		8		10				18
	Rifleman		88	2					90
	MGO			4					4
	MTWS Extra				20				20
	Total	2	696	52	130	10	8	35	933

Source for Tables 1-4 (Natick "Objective Force Warrior Program)

Table 2. Platoon 5 day Battery analysis in Watt/Hours

		Energy (Watt-hours)							
		Wh/unit	6	4	4.5	40	35	185	35	(Wh)
No.		Duty Position	BB516	BA3058 (AA)	BA5123	BA5347	BA5588	BA5590	BA5800	Total
1		PL Ldr	6	32	9	400			245	692
2		PL Sgt	6	32	9	400	70	740	245	1502
3		RTO		32	9		70	740		851
4	Squad 1	Sqd 1 Ldr		32	9	400	70		245	756
5		Rifle Team A Ldr		32	9					41
6		Grenadier		16	9					25
7		Auto Rifleman		32		400				432
8		Rifleman		352	9					361
9		Rifle Team B Ldr		32	9					41
10		Grenadier		16	9					25
11		Auto Rifleman		32		400				432
12		Rifleman		352	9					361
13	Squad 2	Sqd 2 Ldr		32	9	400	70		245	756
14		Rifle Team A Ldr		32	9					41
15		Grenadier		16	9					25
16		Auto Rifleman		32		400				432
17		Rifleman		352	9					361
18		Rifle Team B Ldr		32	9					41
19		Grenadier		16	9					25
20		Auto Rifleman		32		400				432
21		Rifleman		352	9					361
22	Squad 3	Sqd 3 Ldr		32	9	400	70		245	756
23		Rifle Team A Ldr		32	9					41
24		Grenadier		16	9					25
25		Auto Rifleman		32		400				432
26		Rifleman		352	9					361
27		Rifle Team B Ldr		32	9					41
28		Grenadier		16	9					25
29		Auto Rifleman		32		400				432
30		Rifleman		352	9					361
		MGO			18					18
		MTWS Extra				800				800
		Total	12	2784	234	5200	350	1480	1225	11285

Table 3. Platoon 5 day Battery analysis in weight

		Weight (lbs.)								
		Weight/battery	0.59	0.051	0.037	0.64	0.63	2.25	0.45	(lbs)
No.		Duty Position	BB516	BA3058 (AA)	BA5123	BA5347	BA5588	BA5590	BA5800	Total
1		PL Ldr	0.59	0.408	0.074	6.4			3.15	10.622
2		PL Sgt	0.59	0.408	0.074	6.4	1.26	9	3.15	20.882
3		RTO		0.408	0.074		1.26	9		10.742
4	Squad 1	Sqd 1 Ldr		0.408	0.074	6.4	1.26		3.15	11.292
5		Rifle Team A Ldr		0.408	0.074					0.482
6		Grenadier		0.204	0.074					0.278
7		Auto Rifleman		0.408		6.4				6.808
8		Rifleman		4.488	0.074					4.562
9		Rifle Team B Ldr		0.408	0.074					0.482
10		Grenadier		0.204	0.074					0.278
11		Auto Rifleman		0.408		6.4				6.808
12		Rifleman		4.488	0.074					4.562
13	Squad 2	Sqd 2 Ldr		0.408	0.074	6.4	1.26		3.15	11.292
14		Rifle Team A Ldr		0.408	0.074					0.482
15		Grenadier		0.204	0.074					0.278
16		Auto Rifleman		0.408		6.4				6.808
17		Rifleman		4.488	0.074					4.562
18		Rifle Team B Ldr		0.408	0.074					0.482
19		Grenadier		0.204	0.074					0.278
20		Auto Rifleman		0.408		6.4				6.808
21		Rifleman		4.488	0.074					4.562
22	Squad 3	Sqd 3 Ldr		0.408	0.074	6.4	1.26		3.15	11.292
23		Rifle Team A Ldr		0.408	0.074					0.482
24		Grenadier		0.204	0.074					0.278
25		Auto Rifleman		0.408		6.4				6.808
26		Rifleman		4.488	0.074					4.562
27		Rifle Team B Ldr		0.408	0.074					0.482
28		Grenadier		0.204	0.074					0.278
29		Auto Rifleman		0.408		6.4				6.808
30		Rifleman		4.488	0.074					4.562
		MGO			0.148					0.148
		MTWS Extra				12.8				12.8
		Total	1.18	35.496	1.924	83.2	6.3	18	15.75	161.85

Table 4. Platoon 5-day battery analysis in dollars

		Dollars ($)								
		$/battery	110	0.2	2.08	81.83	37.2	79.25	25.13	($)
No.		Duty Position	BB516	BA3058 (AA)	BA5123	BA5347	BA5588	BA5590	BA5800	Total
1		PL Ldr	110	1.6	4.16	818.3			175.91	1109.97
2		PL Sgt	110	1.6	4.16	818.3	74.4	317	175.91	1501.37
3		RTO		1.6	4.16		74.4	317		397.16
4		Sqd 1 Ldr		1.6	4.16	818.3	74.4		175.91	1074.37
5		Rifle Team A Ldr		1.6	4.16					5.76
6		Grenadier		0.8	4.16					4.96
7		Auto Rifleman		1.6		818.3				819.90
8	Squad 1	Rifleman		17.6	4.16					21.76
9		Rifle Team B Ldr		1.6	4.16					5.76
10		Grenadier		0.8	4.16					4.96
11		Auto Rifleman		1.6		818.3				819.90
12		Rifleman		17.6	4.16					21.76
13		Sqd 2 Ldr		1.6	4.16	818.3	74.4		175.91	1074.37
14		Rifle Team A Ldr		1.6	4.16					5.76
15		Grenadier		0.8	4.16					4.96
16		Auto Rifleman		1.6		818.3				819.9
17	Squad 2	Rifleman		17.6	4.16					21.76
18		Rifle Team B Ldr		1.6	4.16					5.76
19		Grenadier		0.8	4.16					4.96
20		Auto Rifleman		1.6		818.3				819.90
21		Rifleman		17.6	4.16					21.76
22		Sqd 3 Ldr		1.6	4.16	818.3	74.4		175.91	1074.37
23		Rifle Team A Ldr		1.6	4.16					5.76
24		Grenadier		0.8	4.16					4.96
25		Auto Rifleman		1.6		818.3				819.90
26	Squad 3	Rifleman		17.6	4.16					21.76
27		Rifle Team B Ldr		1.6	4.16					5.76
28		Grenadier		0.8	4.16					4.96
29		Auto Rifleman		1.6		818.3				819.90
30		Rifleman		17.6	4.16					21.76
		MGO			8.3					
		MTWS Extra				1636.6				1636.00
		Total	220	139.2	108.16	10637.9	372	634	879.55	12990.81

The following analysis is based on the data from the tables above and it should be noted that the power requirement is independent of the weapon systems associated with various mission types. Batteries play a crucial role on the battlefield - they power portable equipment ranging from Night Vision Goggles (NVGs), targeting systems on Javelin missile systems, and detection devices in Nuclear, Biological and Chemical (NBC) alarms. Additionally, and of critical importance, all portable radios rely on batteries to operate. “Effective communications is the key to success on the battlefield” is a popular axiom espoused by many military officers that reveals the importance placed on reliable communications, which depend on batteries.

1. NVG’s, IR Aiming Lights, GPS/ BA-3058

The focus of analysis from the information above is on the equipment associated with the individual squad members that represents the individual soldier and the power requirement of their equipment. However, future concepts include the ability for individual soldiers to have networked communications that include sensors and target designation capabilities. The first set of equipment common to each soldier in the platoon is night vision goggles, infrared aiming lights, and global positioning devices. This equipment utilizes the BA-3058 battery. This battery is equivalent to commercial (AA) batteries. The detailed specifications can be viewed in Figure (2) below.

Figure 3. BA-3058 Specifications

BA - 3058/U

Special Features

- Environmentally safe - Contains 0% Mercury
- 100% final testing
- Long shelf life - up 5 years

Testing Specifications

According to MIL - B - 49030 (Alkaline) as follows:

- Battery Voltage
- Capacity test
- Electrolyte leakage

Technical Characteristics

Nomenclature	Primary ALKALINE Manganese Dioxide battery
Nominal Dimensions	D: 14.5 mm H: 50.5 mm
Nominal Weight	30 gr
Nominal Voltage	1.5 V
Discharge Load	40 Ohm continuously until 0.9 V
Cutoff Voltage	0.9 V
Terminals	2 Flat Surfaces
Operating Temperature Range	-20...... +55°C
Storage Temperature Range	0...... +20°C
Typical Service Life	34 h (20°C)
Shelf Life	5 years
Jacket	Transparent Shrink Sleeve
Jacket Color	Olive Drab (green)
Applicable battery Spec.	MIL - B - 49030
Alternative	BA-58
Disposal	Check with local regulations for proper disposal

Applications

Night vision goggle
AN/ PVS - 5B, 5C, 7A, 7B, 4

Multimeter
AN/ URM - 105,105C

Aviator night vision
AVS - 6

Test set
PSM - 76

Center message
GSQ - 80A

Mobile ew support sys
MLQ - 36

Aiming light infrared
PAQ - 4A

Radiac set
PDR - 63

Many other military applications

To Order

Part number	BA 3058/U
Pcs/Box	12
Pcs/ Master Box	720
Weight (Kg)	23.6
Cubes (m^3)	0.021

Since this battery is equivalent to a commercial (AA) battery they can be used in a variety of applications. The solar power pack can charge eight BA -3058 batteries in twenty minutes based on preliminary tests conducted by Atira technologies. Eight batteries every twenty minutes equals 32 batteries an hour. If each squad member is equipped with the PVPC, a total of 960 BA- 3058 batteries can be recharged per hour. In three hours the entire five day mission battery requirement for BA 3058s can be recharged. The total battery count for BA 3058s in the 5-day mission study is 696, divided by 5 days, equals approximately 140 of these batteries per day that are used. These 140 batteries can be replenished in one hour by five squad members with the

PVPC with a backpack cover solar panel configuration (approx. five square feet of solar panel). In this case the number of batteries needed to be carried can be reduced to 280 batteries. This is based on 140 being used and 140 being recharged. This is a difference of 416 batteries, which saves 21 lbs of weight and has a cost savings of $83.20. This information does not include personal (AA) battery consumption that soldiers often have a requirement for. The data above also makes it possible to determine that the individual soldier power requirement consists primarily of (AA) applications. This analysis is based on the PVPC being directly connected to a (AA) recharging device. The PVPC complemented with the state of the art smart batteries (lithium based batteries) that are wafer thin and extremely light weight could replace completely the (AA) batteries requirement provided the associated equipment can be connected to the device through engineer changes. This indicates that the PVPC can meet the power requirement of an individual soldier in the case of BA-3058s. Since most of the equipment used by a typical soldier is designed around the BA-3058 or (AA) as can be seen in Table (1), it is recommended that the PVPC be designed around the power levels associated with this battery. In other words, the PVPC should be designed to have the capacity to directly power these devices continuously through the use of the lithium batteries identified in the subcomponent list of the PVPC system in chapter II. (See Table 5 and 6)

2. Tactical Light/ DL-123A

The next piece of equipment common among the typical individual soldier is the tactical light, which requires a BA-5123 battery that has been replaced with the DL-123A. This Battery is rated at 3V and the five day requirement is a total of 9 watt/hours per individual soldier. The PVPC can charge four of these batteries within 30 to 40 minutes. If 15 soldiers with a PVPC recharged four of these batteries, the five day's mission supply of batteries could be recharged in approximately forty minutes. It should also be noted that this battery also provides power for communication devices mounted in the helmets of tank crews. Future designs for helmet integrated communications devices could use the PVPC with a helmet solar panel cover configuration to power such devices for individual soldiers. The PVPC could be integrated into a helmet system provided the existing device can be made to the size of a computer chip. (See Table 5 and 6)

3. Thermal Sights/BA5590

The next piece of equipment common among the platoon leader, platoon sergeant, squad leaders, and automatic riflemen as indicated in table 1 are thermal sights, which require the BA-5347. Each automatic rifle man utilizes two of these batteries each day on a five day mission for a total of ten BA-5347s. This battery is rated at 6 volts with a capacity of 65 watt/hours at a 10.8 discharge rate. The PVPC can recharge one of these batteries in approximately two hours. In this case, each soldier only has to carry three of these batteries. This is based on one battery in use while the other two batteries are being charged, assuming each battery last twelve hours. This reduces the number of batteries required to be carried by 97 and saves 62 pounds in weight. The cost savings in this case is $ 7, 937. Tables 6 and 7 provide detailed information from tables 3 and 4 with the PVPC being used. The bottom line comparison is illustrated below. This analysis is based on estimates assuming every battery type has a rechargeable alternative. The analysis is meant to show potential savings. The figures could be more or less depending on how the device is used.

Table 5. Comparison of Totals in Cost from Tables 4 and 7

Battery	BB516	BB3058	BA5123	BA5347	BA5588	BA5590	BA5800	Total
Existing	220	139	108	10,637	372	634	879	$1,2990
PVPC	220	48	74	2,700	86	317	439	$3,986
Savings	0	91	34	7,937	286	317	440	$9,004

Table 6. Comparison of Totals in Weight from Tables 3 and 8 (lbs.)

Battery	BB516	BB3058	BA5123	BA5347	BA5588	BA5590	BA5800	Total
Existing	1.18	35.5	1.9	83.2	6.3	18	15.75	161.85
PVPC	1.18	12.24	1.3	2.112	.315	2.36	7.87	28.58
Savings	0	23.26	.6	81.088	5.985	15.64	7.88	133.27

Table 7. Platoon 5-day battery analysis W/PVPC in dollars

		Battery cost w/PVPC								
			$110.00	$0.20	$2.08	$81.83	$37.20	$79.25	$25.13	$
No.		Duty Position	BB516	BA3058 (AA)	BA5123	BA5347	BA5588	BA5590	BA5800	Total
1		PL Ldr	55.00	1.60	2.08	245.49	0.00	0.00	87.96	$392.13
2		PL Sgt	55.00	1.60	2.08	245.49	37.20	158.50	87.96	$587.83
3		RTO	0.00	1.60	2.08	0.00	37.20	158.50	0.00	$199.38
4	Squad 1	Sqd 1 Ldr	0.00	1.60	2.08	245.49	37.20	0.00	87.96	$374.33
5		Rifle Team A Ldr	0.00	1.60	2.08	0.00	0.00	0.00	0.00	$3.68
6		Grenadier	0.00	0.80	2.08	0.00	0.00	0.00	0.00	$2.88
7		Auto Rifleman	0.00	1.60	0.00	245.49	0.00	0.00	0.00	$247.09
8		Rifleman	0.00	2.40	2.08	0.00	0.00	0.00	0.00	$4.48
9		Rifle Team B Ldr	0.00	1.60	2.08	0.00	0.00	0.00	0.00	$3.68
10		Grenadier	0.00	0.80	2.08	0.00	0.00	0.00	0.00	$2.88
11		Auto Rifleman	0.00	1.60	0.00	245.49	0.00	0.00	0.00	$247.09
12		Rifleman	0.00	2.40	2.08	0.00	0.00	0.00	0.00	$4.48
13	Squad 2	Sqd 2 Ldr	0.00	1.60	2.08	245.49	37.20	0.00	87.96	$374.33
14		Rifle Team A Ldr	0.00	1.60	2.08	0.00	0.00	0.00	0.00	$3.68
15		Grenadier	0.00	0.80	2.08	0.00	0.00	0.00	0.00	$2.88
16		Auto Rifleman	0.00	1.60	0.00	245.49	0.00	0.00	0.00	$247.09
17		Rifleman	0.00	2.40	2.08	0.00	0.00	0.00	0.00	$4.48
18		Rifle Team B Ldr	0.00	1.60	2.08	0.00	0.00	0.00	0.00	$3.68
19		Grenadier	0.00	0.80	2.08	0.00	0.00	0.00	0.00	$2.88
20		Auto Rifleman	0.00	1.60	0.00	245.49	0.00	0.00	0.00	$247.09
21		Rifleman	0.00	2.40	2.08	0.00	0.00	0.00	0.00	$4.48
22	Squad 3	Sqd 3 Ldr	0.00	1.60	2.08	245.49	37.20	0.00	87.96	$374.33
23		Rifle Team A Ldr	0.00	1.60	2.08	0.00	0.00	0.00	0.00	$3.68
24		Grenadier	0.00	0.80	2.08	0.00	0.00	0.00	0.00	$2.88
25		Auto Rifleman	0.00	1.60	0.00	245.49	0.00	0.00	0.00	$247.09
26		Rifleman	0.00	2.40	2.08	0.00	0.00	0.00	0.00	$4.48
27		Rifle Team B Ldr	0.00	1.60	2.08	0.00	0.00	0.00	0.00	$3.68

		Battery cost w/PVPC								
			$110.00	$0.20	$2.08	$81.83	$37.20	$79.25	$25.13	$
No.		Duty Position	BB516	BA3058 (AA)	BA5123	BA5347	BA5588	BA5590	BA5800	Total
28		Grenadier	0.00	0.80	2.08	0.00	0.00	0.00	0.00	$2.88
29		Auto Rifleman	0.00	1.60	0.00	245.49	0.00	0.00	0.00	$247.09
30		Rifleman	0.00	2.40	2.08	0.00	0.00	0.00	0.00	$4.48
		MGO	0.00	0.00	4.16	0.00	0.00	0.00	0.00	$4.16
		MTWS Extra	0.00	0.00	20.80	0.00	0.00	0.00	0.00	$20.80
		Total	$ 220	$48.00	$74.88	$2,700.39	$186.00	$317.00	$439.78	$3,986

Table 8. Platoon 5-day battery analysis W/PVPC in weight

		Battery weight w/PVPC								
		(lbs.)	0.59	0.051	0.037	0.064	0.063	2.25	0.45	
No.		Duty Position	BB516	BA3058 (AA)	BA5123	BA5347	BA5588	BA5590	BA5800	Total
1		PL Ldr	0.59	0.408	0.037	0.192	0	0	1.575	2.8
2		PL Sgt	0.59	0.408	0.037	0.192	0.063	1.18	1.575	4.05
3		R T O	0	0.408	0.037	0	0.063	1.18	0	1.69
4	Squad 1	Sqd 1 Ldr	0	0.408	0.037	0.192	0.063	0	1.575	2.28
5		Rifle Team A Ldr	0	0.408	0.037	0	0	0	0	0.45
6		Grenadier	0	0.204	0.037	0	0	0	0	0.24
7		Auto Rifleman	0	0.408	0	0.192	0	0	0	0.6
8		Rifleman	0	0.612	0.037	0	0	0	0	0.65
9		Rifle Team B Ldr	0	0.408	0.037	0	0	0	0	0.45
10		Grenadier	0	0.204	0.037	0	0	0	0	0.24
11		Auto Rifleman	0	0.408	0	0.192	0	0	0	0.6
12		Rifleman	0	0.612	0.037	0	0	0	0	0.65
13	Squad 2	Sqd 2 Ldr	0	0.408	0.037	0.192	0.063	0	1.575	2.28
14		Rifle Team A Ldr	0	0.408	0.037	0	0	0	0	0.45
15		Grenadier	0	0.204	0.037	0	0	0	0	0.24
16		Auto Rifleman	0	0.408	0	0.192	0	0	0	0.6
17		Rifleman	0	0.612	0.037	0	0	0	0	0.65
18		Rifle Team B Ldr	0	0.408	0.037	0	0	0	0	0.45
19		Grenadier	0	0.204	0.037	0	0	0	0	0.24
20		Auto Rifleman	0	0.408	0	0.192	0	0	0	0.6
21		Rifleman	0	0.612	0.037	0	0	0	0	0.65
22	Squad 3	Sqd 3 Ldr	0	0.408	0.037	0.192	0.063	0	1.575	2.28

		Battery weight w/PVPC								
		(l b s .)	0.59	0.051	0.037	0.064	0.063	2.25	0.45	
No.		Duty Position	BB516	BA3058 (AA)	BA5123	BA5347	BA5588	BA5590	BA5800	Total
23		Rifle Team A Ldr	0	0.408	0.037	0	0	0	0	0.45
24		Grenadier	0	0.204	0.037	0	0	0	0	0.24
25		Auto Rifleman	0	0.408	0	0.192	0	0	0	0.6
26		Rifleman	0	0.612	0.037	0	0	0	0	0.65
27		Rifle Team B Ldr	0	0.408	0.037	0	0	0	0	0.45
28		Grenadier	0	0.204	0.037	0	0	0	0	0.24
29		Auto Rifleman	0	0.408	0	0.192	0	0	0	0.6
30		Rifleman	0	0.612	0.037	0	0	0	0	0.65
		M G O	0	0	0.074	0	0	0	0	0.07
		MTWS Extra	0	0	0.37	0	0	0	0	0.37
		T o t a l	1.18	12.24	1.332	2.112	0.315	2.36	7.875	27.4

B. CURRENT MILITARY EQUIPMENT REQUIRING THE BA-5590 OR EQUIVALENT

Driving the requirement for the ever increasing need for batteries is the growing equipment lists that are needed by ground forces in the conduct of their missions. Both the Army and Marine Corps have thoroughly entrenched the BA-5590 family of batteries as the go-to power source for radios. What follows is a list of the most prominent and widespread equipment using these batteries. (Hamilton, Sablan, Whiteker, MBA Professional Report, p.28)

1. AN/PRC-119A, D, and F

Figure 4. AN/PRC-119F

The AN/PRC-119A, D, F are the manpack configurations of the single channel ground and airborne radio system (SINCGARS). The SINCGARS radios systems are made from interchangeable, modular components sets. The primary component of all SINCGARS radios is the RT-1523 receiver/transmitter (RT). The SINCGARS operates in either the single-channel mode on 50 kHz channels or the high frequency mode. Features of this radio include controllable output power, eight non-volatile preset single channels, and six non-volatile frequency hopping preset channels. It operates over the 30 to 87.975 MHz frequency range in 25 KHz increments. The various radio configurations consist of a combination of basic components. These components include: the RT, vehicular mount, power amplifier, and broadband antennas. The number of RTs, amplifiers, installation kits, and manpack components determine the actual radio configuration and variant. Each radio requires one BA-5590 battery or equivalent providing approximately 32 hours of operating life. (Hamilton, Sablan, Whiteker, MBA Professional Report, p.28)

Figure 5. Satellite Telephone

2. AN/PSC-5

The AN/PSC-5 is a portable, battery-operated, half-duplex ultra high frequency (UHF) radio receiver/transmitter. It is primarily employed for long-range over-the-horizon communications. It weighs approximately 14 pounds including antenna and batteries. The AN/PSC-5 provides two-way voice and data communications by satellite. It operates on the UHF frequency band over the 225- to 400-MHz range. The AN/PSC-5 requires two BA-5590s or equivalent with an expected battery life of 12 hours. (Hamilton, Sablan, Whiteker, MBA Professional Report, p.29)

Figure 6. Secure Tactical Radio

3. AN/PRC-117F(C)-HQ Joint Tactical Radio System (JTRS)

The AN/PRC-117F(C)-HQ covers the entire 30 to 512 MHz frequency range while offering embedded secured communications (COMSEC) capabilities. It is utilized to communicate between ground forces and supporting air assets and is the replacement for the AN/PRC-113. The radio weighs 9.8 pounds without its batteries. It accepts two BA-5590, BA-390A/U, or BB-590 batteries providing an expected operating life of 36 hours. (Hamilton, Sablan, Whiteker, MBA Professional Report, p.29)

Figure 7 (VHF Radio)

4. AN/PRC-150

The AN/PRC-150 provides half duplex HF and Very High Frequency (VHF) tactical voice and data radio communications and is the replacement for the AN/PRC-138. The 20 watt power output is provided by either two batteries or external electrical power. Transmission security is provided either through the KY-99 or its embedded TYPE 1 encryption.ten hours of operation. (Hamilton, Sablan, Whiteker, MBA Professional Report, p.30)

Figure 8. Chemical Sensor

5. M22 Chemical Agent Detector and Alarm

The M22 is an "off-the-shelf" automatic chemical agent alarm system capable of detecting and identifying standard blister and nerve agents. The XM22 system is man-portable, will operate with no human interface after system start-up, and provides an audio and visual alarm. Another critical feature of the XM22 system is a communications interface to support battlefield automation systems. The unit weighs fifteen pounds with two batteries installed that supply power for 32 hours. (Hamilton, Sablan, Whiteker, MBA Professional Report, p.32)

Figure 9 Laser Target Identifier

6. AN/PEQ-1 SOF Laser Marker (SOFLAM)

The AN/PEQ-1 Special Operations Forces (SOF) Laser Marker (SOFLAM) is the SOF-specific laser rangefinding and target designating unit that provides the capability to locate and designate critical enemy targets for destruction using laser guided ordnance. The unit is lighter and smaller than more widely-issued laser markers with better reliability and availability than its conventional counterpart. The SOFLAM is currently in use with army Special Forces and Rangers, Navy SEALs, and Air Force Special Tactics Squadrons. It requires five BA 5590s for 5.8 hours of use. (Hamilton, Sablan, Whiteker, MBA Professional Report, p. 32)

Figure 10 Laser/Rangefinder

7. Ground Laser Target Designator (GLTD) II

The GLTD II provides ground forces with a compact, lightweight, man-portable laser target designator/rangefinder that is ideally suited for precise delivery of laser guided munitions such as Paveway bombs and Hellfire missiles. Through an RS-422 data link, the GLTD II can be integrated into a digitized, day/night fire control and surveillance system. Forward Air Controllers (FACs) rely heavily on GPS devices to locate enemy positions and call in fire against targets. For Operation Iraqi Freedom, the 1st Marine Division employed 19 Ground Laser Target Designator (GLTD) II systems. This system allows FACs and artillery forward observers to measure the accurate range to a target and to designate it for the delivery of laser-guided munitions. (Hamilton, Sablan, Whiteker, MBA Professional Report, p.33)

C. BA-5590 POWER DESCRIPTION AND COSTING DATA

1. BA-5590 Description

The BA-5590 is the most common battery in use in the military. It is approximately 2.3 pounds, and currently costs around $107 (including a $30 disposal fee). A pallet consists of 2000 BA-5590s, takes up 63 cu ft, and weighs 4600 lbs. This battery is rated at 7.2 Ah at 70 ^{0}F and 5.6 Ah at -20 ^{0}F. Used by DoD in numerous applications over the past 10 - 15 years, the BA-5590 is the only lithium technology battery currently available that has a proven successful record in combat situations. With a nominal 200 mA drain in typical use, the battery can provide 28 hours of operation at the minimum operating temperature (36 hours at a normal operating temperature of 70 degrees). Its primary drawback is that the BA-5590 does not have a charge indicator that is cost effective. Thus, this accessory has never been pursued in government applications. It was deemed that charge indicators were too expensive to be used with a disposable battery. As a result of the missing charge indicators, the unofficial DoD policy has been to discard the BA-5590s after 24 hours of operations, even though the actual lifespan of the battery varies between 28 and 36 hours depending on temperature.

As an added safety precaution, in recent combat operations, soldiers in many units were instructed to change their BA-5590s every four hours. (Hamilton, Sablan, Whiteker, MBA Professional Report, p.22)

2. BA-5590 Consumption and Related Costs

BA-5590s are currently in use by every service in DoD. With regards to their communication applications, they power the PRC 104/113/117/119/138 radios, as well as the LST 4, HST 4/5, the Motorola URC and LST, and the MXF-707 series. When used in manpack radios, BA-5590s are typically used in parallel to extend operation time and to facilitate battery change without having to exit the net by powering down the radio.

Due to the extent of their application, the BA-5590 represents the lion’s share of DoD battery consumption. Current DoD peacetime consumption of BA-5590s is not readily available, however, as of 1997, the US Army was consuming about 350,000 BA-5590s per year, which equates to about $22,750,000. To put this in perspective, total Army expenditures for batteries in 1996 was about $100,000,000. Thanks to standardization practices and a growing use of rechargeable batteries, the Army reduced their total battery consumption to $75,000,000 in 2002 . The Marine Corps is also a large consumer of disposable batteries. In 2000, I MEF was consuming approximately $3,000,000 million per year for BA-5590s. Assuming they represent about 25% of the Marine Corps battery consumption, the USMC figure would be approximately $12,000,000 (about 169,000 batteries per year). (Hamilton, Sablan, Whiteker, MBA Professional Report, p.23)

3. Costs Related to Logistic Support for Current Demand

Acquisition costs are not the only consideration when evaluating the use of the BA-5590. Research identified an approximate usage rate of 91 pallets of batteries per month and a total weight and volume requirement of 418,600 lbs and 5733 cu. ft per month. The majority of BA-5590s were shipped by military cargo planes, which therefore displaced other critical cargo. In addition to bumping other critical cargo, the actual costs involved shipping batteries via AMC were tremendous. With 91 pallets a month being consumed, the rate is about three pallets per day. Each pallet (4600 lbs, 64cu ft) would cost approximately $19,320 for AMC to deliver from Atlanta Georgia to Kuwait City. Therefore, daily transportation costs for the BA-5590 via AMC would be about $57,960 or $1,738,800 per month. For proper disposal of spent batteries, transportation back to the states would be the same, an additional $1,738,800 per month. Total monthly cost associated with BA-5590 during Operation Iraqi Freedom = (14,000,000 + 5,500,000 + 3,477,600) = about $22,977,600 per month. (Hamilton, Sablan, Whiteker, MBA Professional Report, p.25)

4. Current Alternatives to BA-5590 Use

Currently, the most applicable alternative to the use of BA-5590s comes in the form of rechargeable batteries. The direct replacement for the BA-5590 is the BB-390 and the new BB-2590. The rechargeable batteries require a power source for initial and sequential charges. The two chargers currently in use are the PP-8444 and the PP-8498. The PP-8498 will charge both the BB-390 and the BB-2590; however, the PP-8444 can charge BB-390s only. Both chargers require AC or DC power to generate a charge. (Hamilton, Sablan, Whiteker, MBA Professional Report, p.25)

a. BB-390B Rechargeable Battery

The BB-390B is a rechargeable, Nickel Metal Hydride battery with "State of Charge Display". It has a nominal capacity of 4.9 Ah at 24.0 volts. It has an operating temperature range of -20ºC to +55ºC (-4ºF to +131ºF). The BB-390B has a nominal weight of 3.880 Lb (1.76 Kg), and is sold in a master carton of 10 batteries each, which weighs 40 lbs and requires about .5 cu ft. Each BB-390B costs about $284, which includes a $30 disposal fee (8). The BB-390B can be recharged about 230 times. At a drain rate of 200mAH, it will provide approximately 24 hours of operation at its optimal temperature (about 66% of the BA-5590 operational time at a similar temperature). (Hamilton, Sablan, Whiteker, MBA Professional Report, p. 25)

b. BB-2590 Rechargeable Battery

The BB-2590 is a newer rechargeable battery designed to directly replace the BA-5590 and the BB-390B. This battery is composed of two separate Lithium Ion rechargeable cells, each with an individual capacity gauge. It has a capacity of 6.0 Ah at

30.0 volts. It has an operating temperature range of -20 to 60 C (-4ºF to +136ºF). Each battery weighs 3.2 lbs and requires .03 cu ft. each. At optimal temperatures, the BB-2590 is expected to provide nearly 30 hours of operational time at a 200mAH discharge rate (about 80% of the BA-5590 operational time). Each BB-2590 costs around $330, plus associated disposal costs which are estimated at $30 per battery. BB-2590s offer up to 1200 recharging cycles. (Hamilton, Sablan, Whiteker, Professional Report, p.26)

Figure 11 Battery Charger

PP-8444 Battery Charger

c. PP-8444 Battery Charger

The PP-8444 charging unit is capable of recharging two batteries of the same type simultaneously, and fully charging these batteries within two hours. The user must select the specific battery adapter that is required for the individual battery type. It can charge numerous types of batteries to include the BB-390, however, it will not recharge the BB-2590. The dimensions of this set are 13.25 inches wide by 10.5 inches deep and 7 inches tall. The unit weighs 12lbs. and requires house or vehicle power to provide a charge for batteries. It has a battery charge indicator and can identify batteries that are internally damaged. Each charger costs approximately $683. The PVPC could replace the mission of this charger in rear or forward positions. (Hamilton, Sablan, Whiteker, MBA Professional Report, p. 26)

Figure 12 Battery Charger

PP-8494 Battery Charger

d. PP-8498 Battery Charger

The PP-8498 charging unit is capable of recharging 2 batteries simultaneously and holding up to 6 batteries of the same or different types in queue for the next automatic charge cycle. It can typically charge up to 8 batteries hands free within 8 hours. It will charge numerous types of batteries to include BB-390's and BB-2590's, which are the rechargeable replacements for the BA-5590. The dimensions of the set are 22.8 inches wide by 14.6 inches deep and 9.0 inches tall. The unit weighs 27.5 lbs and requires house or vehicle power to provide the charge to batteries. In vehicular use, the unit will warn users when vehicle battery voltage drops to 22 VDC and it will shut down at 21 VDC, to prevent completely draining the vehicle's battery. The PP-8498 also contains a battery charge indicator to verify the charge state of any connected battery, and the unit can also identify internally damaged batteries, damaged adapters, and dirty or damaged thermal contacts on BB-390s. Each charger costs approximately $1893. The PVPC can replace the recharging mission of this charger in rear positions or in forward positions. (Hamilton, Sablan, Whiteker, MBA Professional Report, p. 27)

Several conclusions can be made from this analysis. Significant savings can be achieved by utilizing the PVPC in dollars and weight. Given the potential for this technology future designs in networked communications and combat systems should focus on minimizing the amount of power required so that a device like the PVPC can become the primary power source in a integrated system for individual soldiers. Existing equipment and battery recharging requirements can benefit greatly in the near term by utilizing the PVPC as detachable unit with a re-charger designed to hold the batteries indicated above that is used by each soldier. Each soldier would be self-sufficient with his or her power requirement. The analysis makes it clear that there is much to be gained for incorporating the PVPC into the combat load of soldiers. The design should also allow for the PVPC of each soldier to be connected together in a series such that a greater amount of power could be generated to power more complex systems associated with the BA-5590.

IV. USER FAMILIARIZATION AND FEEDBACK

A. USER FAMILIARIZATION

Given an individual soldier load configuration, it is important to determine how the technology can be integrated into the combat load of soldiers. The following information was obtained from data collected by Army Officers of various occupational specialties. The panel of officers that volunteered consisted of occupational specialties in combat arms (infantry), and combat support (supply and maintenance). The panel of officers received a demonstration of Atira's PVPC technology followed by a presentation and a question and answer period. The officers were also allowed time to get hands-on familiarization with the device. They looked at the device along with the various components that are associated with the PVPC - including the solar panel, the PVPC, the wafer thin smart batteries, and the test equipment that measured the power output of the device. The weather conditions of the demonstration provided for an overcast day, which helped to prove the validity of the test and demonstration. The demonstration was designed to show the charging capacity of the PVPC connected to solar panels sewn onto a back pack cover, which consisted of approximately five square feet of solar panel. This system was then connected to a BB-2590, which is described in detail in the previous chapter. The demonstration also had the same battery connected directly to an additional solar panel without the aid of the PVPC. With both solar panels connected to the BB-2590, the test equipment allowed the volunteers to see the difference in power output of each panel. Initially, both panels connected to the PVPC maintained a constant 15V charge into the battery. Then, the demonstrator partially covered each panel to simulate the panels being partially shaded. This was done to illustrate the problem with existing solar technology. The panel connected to the PVPC experienced no change in the charge as could be seen on the test equipment. The other solar panel completely lost all charge because it fell below the charging threshold of the battery. The test showed that as long as there is some ambient light the PVPC can maintain the charge required to re-charge the battery. The immediate reaction of the officers was of disbelief, but after several minutes of questions to the demonstrator they became convinced of the potential of this technology. Some of the questions that were asked were how the technology worked, and how much solar panel area is required to charge the batteries? The demonstration proved to be useful in terms of providing understanding of this technology. Based on the reaction of the participants, future demonstrations will be useful in showing the problem of existing solar technology compared to the solution provided by the PVPC.

B. USER FEED BACK

The officers were then asked, based on the demonstration, to provide data related to requirements determination. The questions were designed to illicit information in the following categories.

1. Functionality- Action the product must be able to perform.
2. Usability- In terms of ease of use and maintenance.
3. Look and Feel- Physical Characteristics of the product.
4. Durability- Able to withstand being dropped, water resistance.
5. Compatibility- Able to be used with multiple systems.
6. Performance- Can operate in extreme environments.

The results are listed below. The results were written into performance type statements.

1. Functional Requirements

- The device shall be able to provide direct power without the use of batteries associated with the equipment during daylight hours in order to eliminate the battery requirement when natural power can be maximized.
- The device shall be able to recharge batteries not in use while providing direct power to equipment being used during daylight hours.
- The device shall be able to reduce the current battery requirement that an individual soldier is required to carry by half in order to reduce the weight of the combat load.

2. Usability Requirement

- The device shall be designed such that no electronic knowledge is required for its operation in order to mitigate the amount of time needed for training.
- The device shall be designed so that a typical 18 year old soldier can easily understand how to maximize power usage between the PVPC and batteries normally used with equipment. Soldiers shall also be able to use readily available tools and equipment for maintenance purposes.

- The device shall come with a comprehensive operations manual as well as a technical manual for emergency field repairs. It shall also be accompanied with a repair kit for solar panels, connectors, etc.

3. Look and Feel

- The device shall not weigh more than 3 lbs and with the subcomponents should not exceed a total of 5 lbs. The solar panels should be applied to all areas of the uniform that has exposure to the sun. The material used for the solar panels should be of a consistency similar to that of fabric.
- The device (PVPC) shall be reduced in size from the current proto-type to the size of a computer chip. This further decreases the overall weight. It shall be designed to connect to the cartridge belt of soldiers with connections for equipment in the top panel. The device should also be consistent in color to blend in with the camouflage pattern of the uniform being worn. Designs shall include woodland, urban, and desert variations.
- The solar panels shall be made of fabric material that can be incorporated to all areas exposed to ambient light. The solar absorbent material shall also be consistent with existing camouflage patterns and colors associated with the area of operation. The thin wafer batteries shall be integrated into the padding of existing straps and padding devices to maximize power storage capacity of the system, which will help the need to carry additional batteries further.

4. Durability

- The device shall be water proof up to a depth of 50ft.
- The device shall be resistant to fall of up to 20ft and shall be able to withstand the rigors found in a combat environment. The device shall be resistant to cracks and breakage.
- The device shall be made of material that can be waterproofed and resistant to foreign matter that can degrade the performance of the device such as extreme dust and sand.

5. Compatibility

- The device shall be designed to be compatible with or should be able to provide power to all electronic equipment associated with the individual soldier in a direct manner while also recharging batteries for no light conditions. (Those types equipment identified in the previous chapter to be most common to each soldier such as the night vision goggles, tactical lights, thermal sights, intra-squad communication devices).
- The device shall be designed to be compatible by having adapters built into it that will allow for a soldier to easily plug in electronic devices for either direct power or for recharging batteries.

- The device shall be designed to work with all solar panels that can be obtained commercially in case the systems solar panels become inoperable due to harsh conditions experienced in combat operations.

6. Performance

- The device shall have the capacity to power several devices simultaneously without interruption. The device shall have indicators to inform the user about information needed to make decisions for maximizing power output.

- The device shall not be degraded by extreme temperatures within the range of -4 degrees C and 40 degrees C. (This temperature range is based on performance requirements associated with lithium batteries similar to those used in the PVPC).

V. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSIONS

To a soldier deployed in remote locations, their power supply is a critical lifeline. By incorporating this new solar technology into their combat loads, they will have a potentially unlimited supply of power.

1. This technology will make each soldier more self-sufficient and less reliant on supply chains.
2. Solar technology offers more benefits than just the power it generates. The utilization of solar technology will lessen the combat load a soldier must carry to support himself by decreasing the number of non-rechargeable batteries needed.
3. This technology will also make it possible to develop networked electronic equipment that will improve the soldier’s ability to communicate and shoot more accurately.
4. This technology will greatly reduce the cost of disposable and rechargeable batteries currently being experienced today in combat operations across the world by U.S. forces.
5. It will also greatly reduce the logistical foot print created by battery supply chains.

B. RECOMMENDATIONS

Bases on the results of this research paper the following is recommended.

1. The PVPC needs to be tested in the field by a platoon size force in a forward position.
2. Each soldier should be fielded a PVPC similar to the proto-type variations with a pack cover solar panel configuration.
3. The soldiers should be exposed to different power requirement scenarios. The results should be recorded as to the flexibility of the PVPC and the imagination of the users in field conditions to maximize power output. The data gathered from such a field test would provide much better user data than could be obtained from this research project.
4. Future combat system designs by the army should focus on minimizing to the extent possible the power requirement of equipment to make them compatible to the power output of the PVPC technology. This technology will allow solar power to become a valid solution to future power

requirements. More research needs to be conducted in further developing the technology through systems engineering to make the device compatible with existing equipment.

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